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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 730

PRACTICAL EXPERIENCES WITH LIGHTNING DISCHARGES TO AIRPLANES

By Heinrich Koppe

Zeitschrift fur Flugtechnik und Motorluftschiffahrt
Vol. 24, No. 21, November 4, 1933

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Washington
December 1933

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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By Heinrich Koppe

There still is a considerable diversity of opinion as to the hazard of lightning in aviation. Thus it is thought that, since there is no direct connection between the airplane and the ground, there could be no force of attraction, consequently, no danger; but that any airplane "accidentally" in the path of a lightning discharge, would be immediately destroyed, or at least set on fire. Both opinions are wrong. In my report on the hazards (reference 1) I have already shown that in principle any aircraft may be and actually has been struck by lightning, whereby the consequences for the airplane were happily trivial according to the three cases then known. To-day, however, we have the accounts of 32 electric discharges to airplanes in flight, which should enable us to make some valuable deductions.

The layer of air surrounding the terrestrial sphere is a poor electric conductor in its lower part; from about 80 km (50 miles) height the conductivity of the air is almost as high as fresh-water. Thus the earth is surrounded by a conducting envelope which the well conducting earth's surface represents a condenser whose one plate, the earth, is mostly negatively, the other, the conducting envelope, is always positively charged. Between the two is a potential gradient of about 200 kV and a continuous electric current flows from the conducting envelope to the earth, amounting to approximately 1360 amperes figured for the whole earth's surface. The carriers of this electric current are the ions which move at a speed depending on the potential gradient and the air density. The concentration of such electricity conductors of the same sign represent a certain electric charge, the so-called "space charge." Under the effect of the high potential gradient between the conducting envelope and the earth's surface and such space charges an electric field is formed, whose intensity at the ground is quite considerable (100 V/m) but rapidly decreases upward. The areas of

*"Praktische Erfahrungen aus Blitzschlägen in Flugzeuge." Z.F.M., November 4, 1933, pp. 577-586.

equal potential hug, as a rule, the earth's surface, elevations or free-floating conductors cause these areas to shift and as a result a local rise in field density. Consequently, a high tree or tower, a captive balloon or kite may raise the potential gradient very considerably at its tip. By the same argument every free-floating conductor sets up a disturbance of the electric field, and which becomes so much greater the longer and more pointed the shape of this conductor is perpendicular to the areas of equal potential (fig. 1). Thus, a long airship will cause less interference than a small airplane with extended trailing antenna or a free balloon valving gas with rain-soaked drag rope. Aircraft can adapt itself readily to the potential of its surrounding, although it can of course conduct or produce its own charges, which however are small and therefore do not cause much interference.

But the normal state of the electric field of the air can under certain weather conditions undergo profound disturbances which produce a tremendous rise in potential gradient. This occurs above all through the formation of high electric charges in the air, that is, space charges, which usually are bound up with precipitations (fig. 2). The so-called Lenard effect through the bursted large rain drops as well as the spraying back of small drops when two varyingly large rain drops are flung against each other, or the chipping off of very minute fractions of icicles from the snow crystals in snow storms, all play an important role. In every case it always stipulates a separation of many individual, small, light particles with negative charge upward from few heavy large particles with positive charge downward. In this manner enormous electric charges are produced especially with strong vertical motions and precipitations which as independent space charges create such a strong potential gradient as to lead to repeated equalization through spark discharges, i.e., to thunder storm (fig. 3). Potential gradients of from 1 to 4 kV/cm have been recorded in the vicinity of thunder clouds. But, if this gradient has grown to 10 to 15 kV/cm at any point, it may at a large raindrop rise to 30 to 40 kV/cm as result of the shifting of the areas of equal potential. Then the drop emits brush discharges which rapidly advance in field direction even if the field intensity is low. This advance of the electric charge is at the rate of 100 km/s; which would be the speed of lightning.

The lightning is no oscillating process but an aperiodically damped forward push of an electric charge from cloud to cloud, from cloud to earth or vice versa. The discharge conduit is a tube of ionized air of several decimeter diameter through which a current of the order of 10,000 amperes passes within about 1/100 sec.

The lightning discharge therefore begins at a point at which the potential gradient exceeds the critical amount of from 30 to 40 kV/cm. Now, every aircraft causes a rise in the already existent field intensity and can thus release a lightning discharge. Since an airplane with a 70 m trailing antenna is capable of raising the potential gradient to 10 to 20 times the amount of the undisturbed field, it is bound to produce a spark discharge when flying through a cloud of only 2 to 3 kV/cm potential gradient. This readily explains the greatest number of known cases of lightning discharges to airplanes. Accordingly, no "accidental" flight through the path of the lightning, but release of a lightning discharge with a potential gradient which otherwise would not suffice for an independent discharge.

For reasons of simplicity and brevity the term "lightning discharges" as used hereinafter, denotes electrostatic discharges over the airplane, which, released from the airplane itself have, as known by experience, much less effect than those observed otherwise on the ground.

As previously stated, I have the records of 32 cases, some collected from various sources, some the results of my own investigations.

Of these, 23 occurred on German, 4 on English, 2 on Swedish, and 1 each on Czechoslovakian, French, and Belgian airplanes. Not one single absolutely authentic case of lightning striking a U.S. airplane has ever been observed, as far as I have been able to find out. The large quota for German airplanes is obviously a proof of German air transportation activities, particularly of much and able "bad weather" and cloud flying.

There was only 1 record prior to 1925, 2 each in 1925 and 1926, 1 in 1928, 11 in 1931, 9 in 1932, and 6 so far in 1933. These figures reveal increased bad weather flying as well as the more general use of wireless equipment.

Of the 32 cases, 2 continuous discharges due to Saint Elmo's fire and 1 induced discharge on a glider are eliminated, which leaves 29 cases of lightning striking an airplane in flight (fig. 4).

Classified as to their effect on the airplanes we have:

1) Light discharges, the antenna being burnt off, the radio slightly damaged but no damage to airplane;

2) Medium discharges, antenna being burnt away, radio considerably damaged, airplane slightly damaged;

3) Heavy discharges, antenna destroyed, radio almost destroyed, considerable airplane damage or danger of fire.

In accord with it there were 7 light, 9 medium, and 13 heavy discharges.

One noteworthy feature is presented by the grading of the hits according to their severity on the different airplane types.

Of the 4 discharges to wooden airplanes none were light, 1, medium, and 3, heavy. Of the 8 hits to the mixed design type none were light; 2, medium, and 3, heavy. In the 17 all-metal airplanes, 7 were light; 6, medium, and 4, heavy discharges.

The very fact that, of 29 airplanes 26 were struck with extended antenna manifests that the electrostatic range of influence of the airplane materially increased with the antenna and the thereby produced strong rise in potential gradient was responsible for the release of an electric discharge. It was apparently immaterial whether the radio was in operation or not; neither does there seem to be any connection between the operating state of the wireless equipment and the severity of the discharge.

Several lightning discharges were accompanied by very severe and not at all harmless air pressure actions. None of the wooden, but 4 of the mixed, and 1 of the all-metal airplanes were hit.

Effects of lightning discharges on occupants were observed in two cases and then only in wooden airplanes.

Magnetization of steel components which produced a compass disturbance after the discharge occurred in 1 case on the wooden types, 7 times in the mixed, but none in the all-metal types.

The meteorological conditions accompanying the lightning discharges were as follows: In 2 cases the airplane was in the vicinity of thunderstorms; in 5 cases the flight was right through the storm itself. In the other 22 cases the hits occurred without noticeable electric discharges before or after striking. Seven cases reported flight through a squall cloud, 10, hail, and 16, snowstorm.

The classification of lightning discharges by months shows: 6 for April, 4 for March, 4 for October, 3 each for July and September, 2 each for December, January, and May, and 1 each for June and August. There is no record of any discharge in November.

An analysis of these cases reveals the following: As far as the meteorological conditions are concerned the greatest frequency of lightning discharges does not occur during the months of greatest thunderstorm frequency. Judging the number of flights according to the seasons, the winter months show a comparatively greater frequency. The greatest number of lightning discharges occur undoubtedly in the spring, the fall months also show greater frequency.

Together with the meteorological conditions at the time of discharge and an investigation of the individual weather conditions the electric conditions of the air are somewhat as follows: The probability of lightning discharge in flight through a thunderstorm is undoubtedly very great. But the aestival thunderstorms are timely noted by the weather bureau and the pilot and so avoided as much as possible. When they must be flown through, it is done very cautiously, and with reeled-in antenna.

As a rule, one is less careful when there are no visible indications of thunderstorm. The electrostatic charge is undoubtedly too much underestimated under the various weather conditions. We know that the discharge electricity can produce enormous space charges; especially when large rain drops are dispersed or snow crystals are split off. This is always bound up with considerable vertical motions in the air. Hail and sleet? occur only with very pronounced upward motions which we designate as gusts. And it is found that the lightning discharges occurred especially frequently in clouds which from the outside looked like gusts, which revealed the peculiar shapes of the upward motion on its upper side and were accompanied with driving snow or even hail. Evidently enormous electric charges are produced in a heavy snowstorm, that is, high potential gradients, so that an airplane with trailling antenna can easily release a spark discharge. In all these cases and as attested by ground observations the electric discharge released through the airplane is the only one.

An airplane with antenna trailing entering an in itself strong field may be raised to 10 to 20 times its amount. Theoretically, the maximum potential gradient should occur at the tip of the antenna and around it; there the areas of equal potential are shifted so that critical field intensities of from 30 to 40 kV/cm are readily reached. It is unfortunate that the antenna is usually difficult to see from an airplane; it probably would show Saint Elmo's fire in night flight as observed on the propellers. The fact that Saint Elmo's fire was repeatedly observed on propellers and wings proves, however, that the potential gradients must be very high at those points. Accordingly, the antenna also acts as equalizer and the airplane evidently assumes the potential of an area which does not pass through the airplane but beneath it, that is, lies between exhaust and antenna tip (fig. 5). Undoubtedly electric current flows in the strong field from antenna to engine, exhaust and propeller even without stroke-like discharges. With the high potential gradient around the airplane the air is strongly ionized; the small ions are drawn to the airplane at several times the flying speed. All this may, without lightning discharge or prior to it, lead to disturbances as actually observed at various occasions. In one case the antenna-transmitting current dropped 50 percent shortly before the spark discharge. Spark contacts and strong atmospheric disturbances in reception were also noticed occasionally, although this is not always the case; mostly the lightning discharge came without warning. Admittedly the suddenness of the flash is altogether understandable, since the airplane is able to carry, so to speak, its field at high potential gradient and to approach a strongly concentrated space charge very rapidly.

There also is a record of three cases of lightning discharge in airplanes without antenna: two, in wooden airplanes flying through thunderstorm, and one in which lightning hit twice. This particular airplane, a biplane, all wood, (fig. 6) attempted to fly through the front of a thunderstorm. There was first a discharge through the right wings in the clouds, in heavy snowstorm. A few seconds later lightning hit the left wings very severely. The pilot was almost blinded and felt slightly lame which effects, however, soon disappeared. The remarkable thing is that in both cases the discharge passed through the wings near the wooden struts, and did not follow the fuel line. In another case a twin-engine airplane of the mixed type released a lightning discharge while flying through clouds in a heavy snowstorm. The discharge passed over one of the outboard engines and caused temporary ignition disturbance. The fabric covering of the wings, as well as the ribs and fittings were damaged considerably.

There is no connection between the type of airplane and the frequency of discharge. But the fact remains that the damages to wood and mixed type airplanes are usually more severe than to all-metal airplanes. And this is also readily understood. The all-metal airplane offers the electric discharge a very convenient path especially in the closed outer skin. But it is particularly dangerous, regardless of type, when the discharge passes into the airplane, and the all-metal types are not immune as we shall show.

Many consider fire as the most dangerous consequence of a lightning discharge. There is no absolutely authentic case in which lightning set the airplane on fire; on the other hand it cannot be denied that in some cases the danger of fire was imminent. The fuel and oil in the closed metal tanks and pipes cannot burn before these pipe lines or tanks have been destroyed. Gasoline lines have never been directly hit by lightning nor destroyed by arcs. There is no danger of further burning of parts heated to or above the flash point during the very short discharge, when these parts are well cooled. But the appearance of arcs within the airplane is much more serious.

Since the antenna releases the lightning discharge in most cases and offers the discharge the most convenient path the attached radio equipment is above all exposed to damages. They may be harmless sparking contacts, burning of pipes or fuses; but they may equally destroy switches, coils, generators, etc., and even burn out the whole radio. In 19 out of 26 cases the antenna was burnt off at the point where it emerges from the fairlead. In several cases the fairlead itself was more or less damaged. But in all cases the radio was put out of commission. (See fig. 7).

Damage to outside parts of the airplane was mainly confined to the wooden and the mixed-type airplanes. There the electric charge must clear the path to better conductors within the airplane, the outer skin is destroyed. Thus wings covered with wood or cloth were damaged when the path led over the antenna egg or over the wires to the position lights. Such damages (fig. 8a,b) may consist of small, round scorched holes in the wood or fabric, although tearing and ripping off of larger pieces is not unknown. Steel is a poor conductor for the lightning current; for which reason lightning does not follow steel cable very often, but so much greater is the danger of fusion by current contacts. For instance, note the burnt 1 mm steel wire fin braces on the wood-fabric airplane (fig. 9).

For the same reason the lightning discharge does not follow the engine shaft to the propeller but generally jumps over from the engine, cowling or radiator (fig. 10). That propellers in particular act as equalizers is well known and confirmed by the frequently observed Saint Elmo's fire. This may readily lead to current contacts with pronounced heating from airplane to propeller, but also from propeller to the surrounding, highly ionized air (fig. 11). Hence the traces of fusion on the radiator, cowling and other contact points in all-metal airplanes (fig. 12).

If the lightning follows the antenna into the airplane it generally results in very severe and dangerous damage. Even the all-metal airplane is not immune. When the antenna fairlead forms a convenient direct path to the inside lightning follows it and it merely remains a question of arrangement and design at what point it finds this path inconvenient and tries to find a better one to the engine and the propeller, where it then establishes a contact and usually results in severe and dangerous arcs (fig. 13). This not only produces a fire hazard but it also jeopardizes other vital parts of the airplane (fig. 14).

A lightning discharge within an airplane constitutes a direct or indirect hazard to the various installations. This applies in particular to electric equipment, which is destroyed, fuses burnt or blown out, etc. The current supply for vital equipment is disturbed, if not altogether so seriously damaged as to render temporary repairs impossible during flight. In one case the electrically operated fire extinguisher was set off by lightning.

Several severe lightning discharges to airplane of the mixed type were accompanied by air pressure effects which wrought considerable havoc on the airplanes. Nearly all lightning discharges manifested pressure or shock effects, which, however, were frequently less observed under the stronger impression of the other effects or overlooked altogether in the natural startling during the flash.

In the previously cited case of lightning striking a twin-engine airplane without antenna, such a strong draught of air blew through the cabin window toward the pilot's seat that parts of the wooden paneling was ripped off and thrown into the pilot's lap. In another case five of the eight windows in the pilot's hood together with their metal frames were torn out and some of them flung into the propellers, thus causing additional damages. In this particular case the connecting doors were either blown open or wedged tight and cloth covering was torn off. In two other cases on airplanes of the same type practically the whole covering on the bottom of the fuselage was destroyed. In the first case (fig. 15) the pilot did not notice the hit except for a hard bump, which he first ascribed to colliding with a large bird until the simultaneous destruction of the radio and other indications of a lightning discharge convinced him otherwise. In the other case (fig. 16) the damages were almost identical. The 1.5 mm heavy plywood covering, nailed and glued to the framework, was wrenched from its base leaving the nails exposed as much as 5 mm.

Very obviously this was due to the enormous pressure effects which can be explained only by electric phenomena. There also was one very conspicuous example of so-called electrostriction in the above case. The 0.5 mm gage brass antenna fairlead was inwardly compressed with such powerful force (fig. 17a) so as to crush the tube in about 10 close, solid lobes, causing it to split in about 20 small, long strips. The crushing pressure was so great as to leave the imprint of the antenna wire (fig. 17b).

The danger of injury or death to occupants of an airplane by lightning is much overestimated. Admittedly the human body is - apart from the protecting skin - a fairly good conductor and, if used as such by the lightning current, there is no doubt at all as to the final outcome. In the airplane, even if of wood throughout, there are, however, so much better conductors, such as pipes, rods, cables, etc., right next to the human body which lightning always will prefer; in contrast to the free balloon where lightning prefers the human body to the hemp ropes. Thus we know of only two cases of effects of lightning on occupants; both in wooden airplanes. In one case the pilot wore his head set during a heavy discharge and was temporarily stunned or dazed. In the other case it resulted in a very slight, brief paralysis without after-effects. We also must mention the stunning effect of an adjacent lightning discharge, evidently owing to induction effect in the metal components on the pilot of a glider. A notable fact is that lightning discharges to fully occupied, large transport airplanes have never caused any bad effect or signs of uneasiness in the passengers.

Even if the discharge has passed through the airplane harmlessly, it sometimes leaves an after-effect which may endanger the safe continuation of flight; this is the magnetization of metal parts around the compass. Steel tubing, as well as cables, which forms a part of the lightning path or happens to be near a heavy discharge, is heavily magnetized. This may lead to compass deviations strong enough to make it practically useless. Of course, magnetization through lightning discharge occurs only in wood and mixed type airplanes; in the latter type in seven cases out of eight. The magnetization may be so great and lasting as to preclude dependable functioning for a long time. No magnetization has been observed nor is any expected in all-metal airplanes of aluminum.

The conclusions to be drawn from these practical experiences are as follows.

From the meteorological point of view, advice and personal training of pilots can certainly insure timely appreciation and avoidance of imminent dangerous weather conditions in many cases, although not in all cases. For strong electric space charges can so suddenly be formed locally as to defy recognition when flying in clouds. All squall clouds, that is, towering cumuli are precarious; especially the numerous squalls in the spring of the year. Marked distortions on heavy stratus clouds also prove the existence of vertical movements and, when accompanied by precipitation, of disturbances in the potential gradient within. Hail and sleet are direct danger signs; a heavy snow storm is never without strong electric charges.

According to the numerous lightning discharges to airplanes flying in snowstorms the electrostatic conditions are such as to indicate the existence of marked pressure gradients even in the winter months.

Analyzing the recorded lightning hits in their effects on the airplane according to current intensity we find in most cases an order of magnitude of 10 kA, which is in acceptable agreement with the measurements and calculations from ground observations. The boundary between "medium" and "heavy" discharges to airplanes lies between 5 and 25 kA.

An analysis of the strength and forces on the antenna fairlead crushed by electrostriction would give an amperage of more than 100 kA; according to that the assumptions made for this analysis require perhaps further experimental verification. When Saint Elmo's fire, a steady brush discharge, is observed, which, although it occurs quite frequently in day flying, is seldom noticed, there is a steady direct current flow from antenna to engine, propeller, and wings, etc., or vice versa, depending on the direction of the potential difference. This current is of the order of 0.5 to 3A for large multi-engine airplanes. The potential difference bridged by the lightning protector depends upon the length of the discharge. For a 2 km length one can figure with a potential difference of around 100,000 kV. In most cases, as far as airplanes are concerned, it probably involves the equalization between two space charges within a cloud, although there is a record of an airplane having released lightning discharges between two clouds. Unfortunately lightning discharges to airplanes are not usually accompanied by simultaneous ground observations, except in a few cases. In one case the path of the stroke from the cloud over the airplane could be clearly observed on the ground. The low-flying airplane probably always will cause a discharge to ground. The high-flying airplane produces first a discharge within the strongest electric field which, however, can easily develop to potential balance over a large zone, that is to ground also.

The space charges being frequently locally concentrated a very strong horizontally directed potential difference can exist which is especially hazardous to airplanes with long, trailing antenna and to towing gliders.

If in doubt the trailing antenna should be immediately reeled in. And here it is very desirable to have some kind of warning device which indicates direct and immediately the electric conditions of the air, and particularly the potential gradient. Such instruments are available or quite easy to make; for instance, a neon tube on a sounder would serve the purpose. Perhaps the radio could be used as indicator.

The rise in potential gradient to critical value occurs with the high flying speed and the many times higher speed of the small ions in the strong field at such abnormal rate that, as substantiated by experience, the warning would arrive too late in most cases.

Reeling in 70 m of antenna is a tedious and disagreeable task. It is therefore necessary to provide that the antenna can be expediently "grounded", i.e., connected to the large metal masses of the airplane. Moreover, such safety switches must insure that the lightning discharge actually follows them. Then too, it is expedient to offer the discharge in all cases - even without actuation of grounding switch - a more convenient path than the antenna which leads into the airplane; or in other words, prevent under any and all circumstances the stroke from passing through the fairlead to the inside of the airplane. The usual lightning protectors in the antenna fairleads do not seem to me to give this absolute guarantee. For, once the electric charge has reached the antenna fairlead, the straight path over the antenna to the reel is indeed extremely tempting. To be absolutely sure, an obstacle must be provided for the discharge in the antenna line leading to the fuselage; for instance, any sharp bend (fig. 18). The conductor should shunt the discharge before this bend to the engine by the shortest route. With the installations of the antenna fairleads as practiced now there is an almost rectangular bend at the end of the fairlead. Following a stroke of lightning to a Swedish transport airplane I suggested the following, very simple lightning protection which from the wireless point of view at least has functioned perfectly and is today used in a number of other foreign airplanes (fig. 19).

The underlying idea is to offer the lightning current a very convenient path to the engine before it reaches the antenna fairlead. This is insured by a stirrup which surrounds the antenna in the fairlead and which forms a direct connection with the engine. In rest position the stirrup serves as arc-over fuse without interference with the radio operation. It is easily pushed down to contact with the antenna, which then is easily and safely pulled in.

Still greater security is assured when giving the antenna fairlead a slight forward slope as suggested in figure 20a and b. The sharper the bend in the antenna the quicker will the lightning current abandon it and take the more convenient path offered.

To shunt minor partial discharges from the radio equipment it is advisable to provide another, similar protection between the antenna reel and the change-over switch.

The cited protecting devices do not prevent a stroke of lightning; the trailing antenna is usually lost when lightning strikes it, and it is difficult if not altogether impossible to install then an emergency antenna. Besides, a certain amount of radio communication is desirable for purposes of navigation especially in clouds. Here is where a fixed antenna over the fuselage has proved very satisfactory. Its air resistance is low, although the radiation conditions are admittedly less propitious than with the long, trailing antenna, at least for the long waves still used for the present, and for which it should be considered only as a substitute.

The propeller is very frequently damaged, being a particularly strong equalizing structural component. All-metal propellers are more proof against such damages than metal-tipped wood propellers; in any case the tipping should not be too thin and should form a good connection with the engine. This can be insured by shields and copper rings inserted at the hub (fig. 19). It at any rate prevents the dangerous and destructive arcs.

In various cases of lightning discharges to mixed-type airplanes, the current entered the wing tips and took the convenient path offered by the antenna weights or the wires to the navigation lights. This is apt to cause more or less damage to the wing covering, but may be prevented by interconnecting all conductors and bonding as shown in figure 19. The conducting aluminum bronze coating of the wings can then also be connected to the lightning shunt.

All electric wires within wood surfaces should be housed in metal conduits and connected to the lightning protection plates on the outer skin and the engine. The same applies to the electric leads to the tail.

Fuses protect the electrical equipment against destruction through abnormal current charges. With the enormous excess voltage and amperage of a lightning discharge the fuses burn out explosive-like. But the electrical equipment can still be seriously impaired by a discharge despite the safeguarding fuses. For which reason, it is advisable to carry an emergency set of nonelectrical equipment, insofar as it is necessary to continue the flight. In one particular case - discharge in clouds above the North Sea - the flight was successfully carried through with the pneumatic turn indicator and azimuth gyroscope after the electric horizon and the compass had failed.

One very disagreeable after-effect of a lightning discharge is the occasionally very heavy air pressure effect. It is caused by electrostriction, i.e., the parallel electric current paths are mutually attracted, thus attracting all parts in the vicinity of the main path of the current. It is well conceivable that a shield fitted on the bottom covering offers a certain protection against ripping in electrostriction, being itself conducting and attracting the ionized air.

The occupant of an all-metal airplane needs no special protection. Even the steel tube fuselage offers, as a general rule, ample protection. In wooden airplanes all metallic parts should be bonded and form as direct a connection with the engine as possible. For extra precaution the pilot's seat may be shielded. The same applies to gliders in which adjacent lightning discharges may produce unpleasant induction effects. The hazard in night flying is the blinding of the pilot by an unexpected discharge to the extent of losing control.

In conclusion it may be said that airplanes are not "hit" by lightning, neither do they "accidentally" get into the "path of a stroke". The hits to airplanes are rather the result of a release of more or less heavy electrostatic discharges whereby the airplane itself forms a part of the current path.

The hazard to aircraft from lightning is frequently much overestimated. None of the discharges to airplanes known heretofore has fortunately caused any permanent damage to passengers and the damage to material was in most cases small, nor was any airplane forced to land immediately even after a heavy discharge.

Lightning discharges to airplanes in flight can be minimized by appropriate weather forecasts and training of the pilots.

The long trailing antenna itself may release an electric discharge if there is a high electrostatic potential gradient.

The effect of such discharges is less on the all-metal than on the mixed or the all-wooden airplanes.

The entry of lightning current into an airplane is always very serious no matter what the type of airplane, but can be avoided by appropriate shielding.

The radio must be especially protected. A fixed antenna can be used even with a high difference in potential. It serves as important substitute when the trailing antenna is lost.

The heavy pressure effects due to electrostriction are serious secondary phenomena.

Failure or disturbance of important instruments or equipment vital to maintaining flight attitude, navigation or general safety constitute direct hazards.

The forces of nature released in a storm are a danger to any work of the human hand, particularly the airplane. But it is less the lightning which we have to fear than the mighty air movements which can toss the airplane about as a powerless ball of the elements to the limit of its strength; more dangerous than lightning are the squalls, the formation of ice and the hailstorms, as striking example of which note the severe damage from hail on a glider which had been carried up into a thunderstorm (fig. 21).

Translation by J. Vanier,
National Advisory Committee
for Aeronautics.

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1. Koppe, Heinrich: Von dem Gefahren des Luftmeeres. Z.F.M, vol. 20, 1929, p. 367.

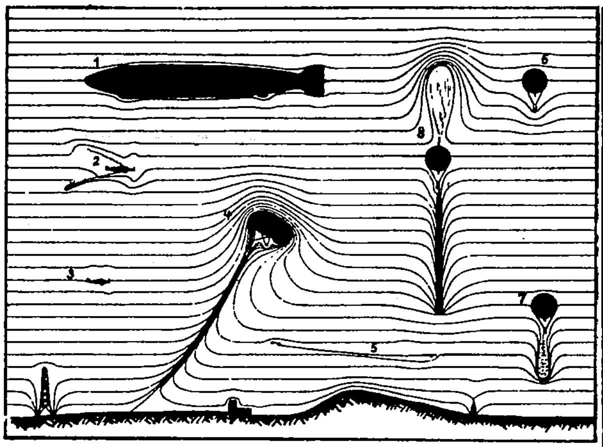


Figure 1.- Aircraft in an electric field.

1, Airship without antenna.
2, Airplane with "
3, Airplane without "
4, Captive balloon grounded.
5, Towing glider.
6, Free balloon.
7, Free balloon (jettison ballast).
8, Free balloon (valving gas with wet drag rope).

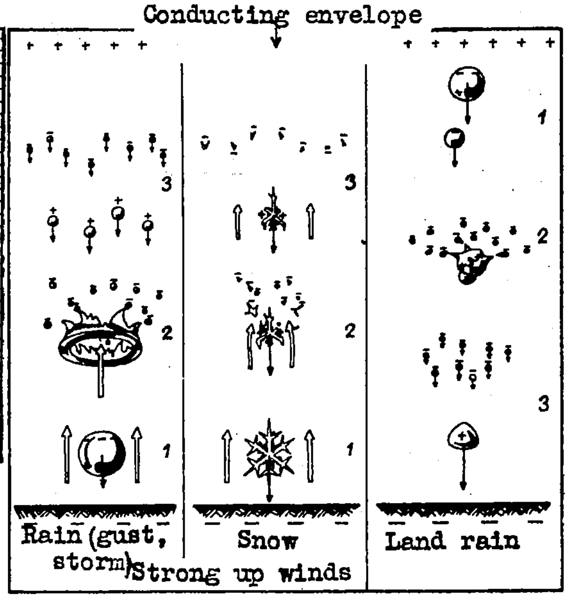


Figure 2.- Formation of electric space charges during percipitation.

Left: bursting of large rain drops at sinking speed of 8 m/s (Lenard effect).
Center: splitting of small icicles of snow crystals in snow storm (Kähler).
Right: separation of small droplets when colliding with varyingly large rain drops (Elster and Geitel).

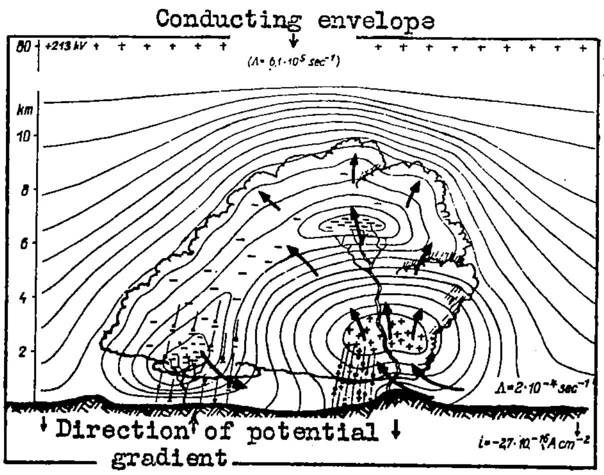


Figure 3.- Electric structure of storm. The large drops burst in the zone of strongest up wind; the large positive residual drops float below on the vertical air current; the negative small droplets are whirled upward. Potential gradient, percipitation and lightning frequently positive at storm front, negative at back.

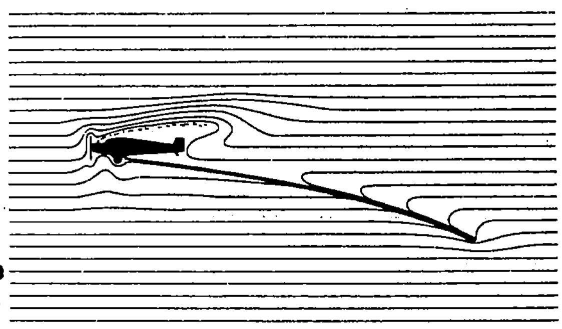


Figure 5.- Airplane with antenna in electric field.

a, 3 without trailing antenna
b, 26 with " "
c, 4 wood
d, 8 mixed
e, 17 all-metal
} Airplanes (c–e)

f, 7 light
g, 9 medium
h, 13 heavy
i, 1 light
j, 4 medium
k, 5 heavy
m, 6 light
n, 1 medium
p, 2 heavy
q, 3 medium
r, 4 heavy
s, 10 out
t, 9 in
u, 3 heavy
v, 2 medium
w, 6 heavy
x, 6 medium
} Discharges (f–x)

A, Magnetization.
B, Air pressure effect.
C, Effect on occupants.
D, 2 ↯ 2 near
E, 5 ↯ 5 in
} storm (D–E)
F, 7 ▽ 7 gust front
G, 10 ▲ 10 hail
H, 16 ✦ 16 snow storm

Classification of 29 discharges to airplanes

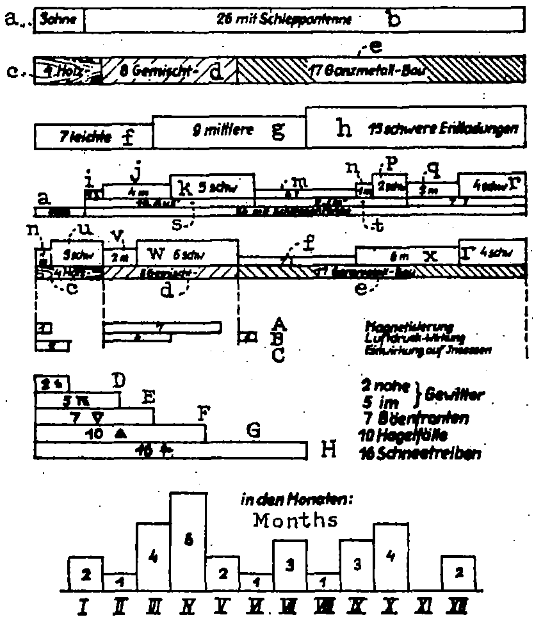
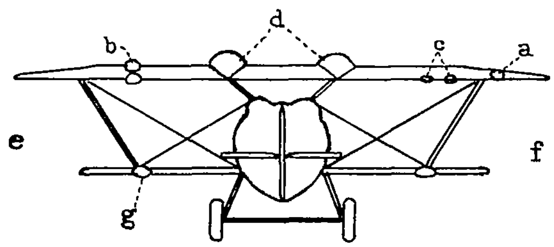


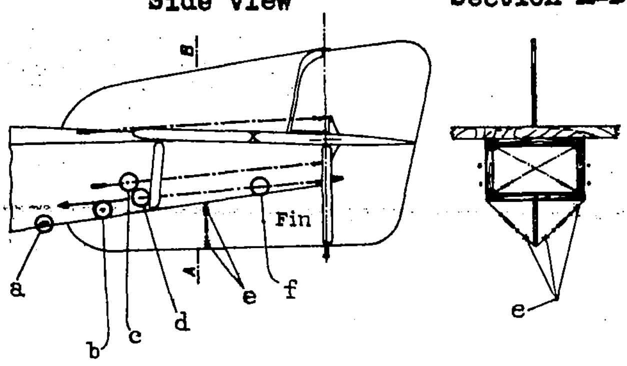
Figure 4.- Lightning discharges to airplane.



a, 1st.stroke.
b, 2nd. "
c, traces
d, fuel tanks
e, right
f, left
g, fusing and welding effect

Figure 6.-Double discharge to "Berline-Spad"; pilot Sladek,Oct.15,1925

Side view Section A-B



a, tear due to pressure effect
b, arc outward, antenna weight burned
c, HR-S light trace of fusion
d, SR-S light trace of fusion
e, brace wires fused
f, 3 rudder-cable strands fused

Figure 9.-Damage to a wood-fabric airplane

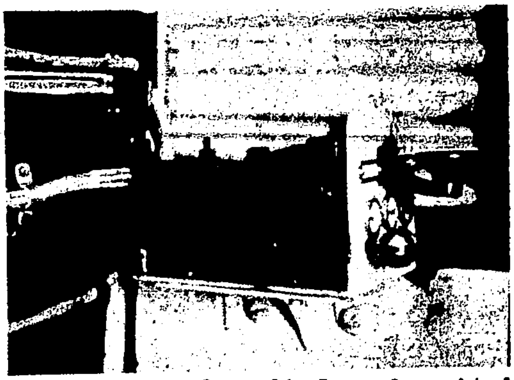


Figure 7. Radio dial and switch burned out.

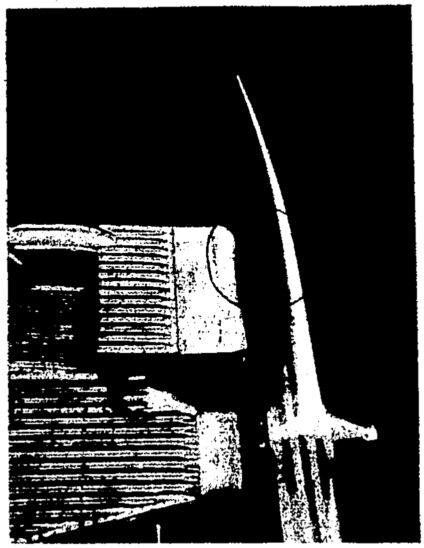


Figure 10. Arc from body to propeller.

(a) Outward arc

(b) Tear due to pressure effect.

Figure 8. Damage to a wood fabric covering.

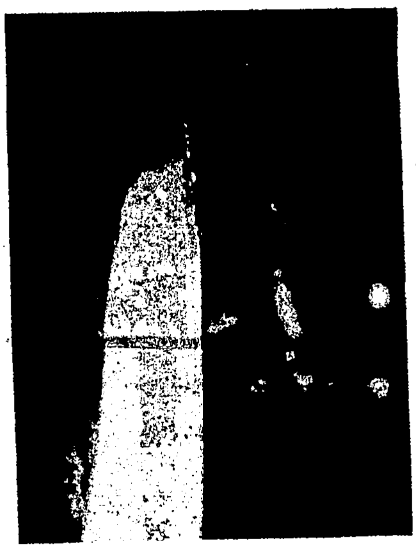


Figure 11. Metal tipping damaged at trailing edge of propeller.

Figure 12. Trailing edge of all metal propeller damaged.

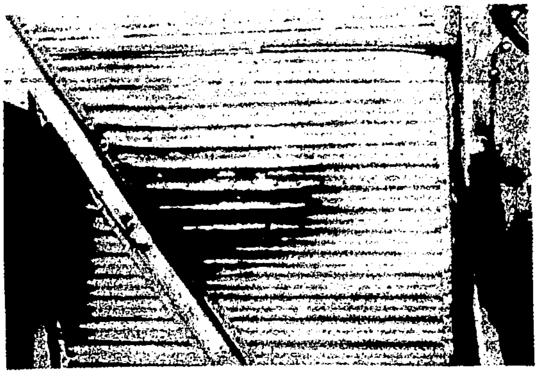


Figure 13.- Five traces of arc in an all-metal airplane.

Figure 15.- Destruction of fuselage covering due to pressure effect (according to L'illustration 10/24/31)

Figure 18.- Arcing of lighting current on a sharp bend.

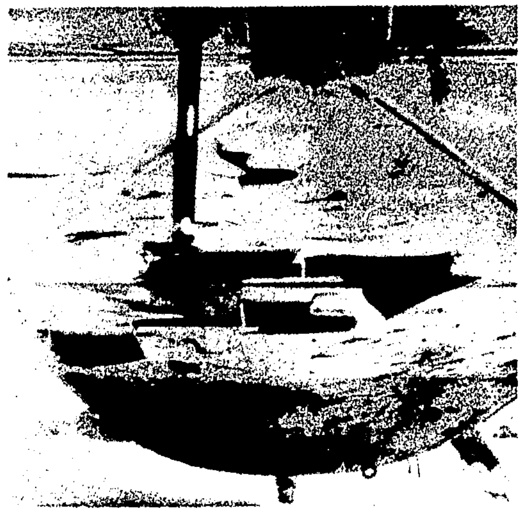


Figure 16.- Destruction of fuselage covering due to pressure effect.

(a) Tubing between two reenforcements.
(1) Undamaged tube.

(b) Collapse at tube end.
(2) Imprint at edge of break.
(3) Fusion of antenna.

Figure 17. Collapse of antenna fairlead-electrostriction.

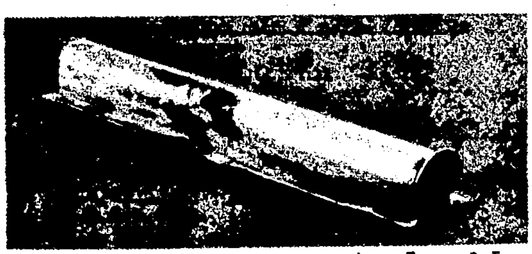


Figure 14.- Arc on control cable housing.

Figure 21.- Damage to glider due to hail.

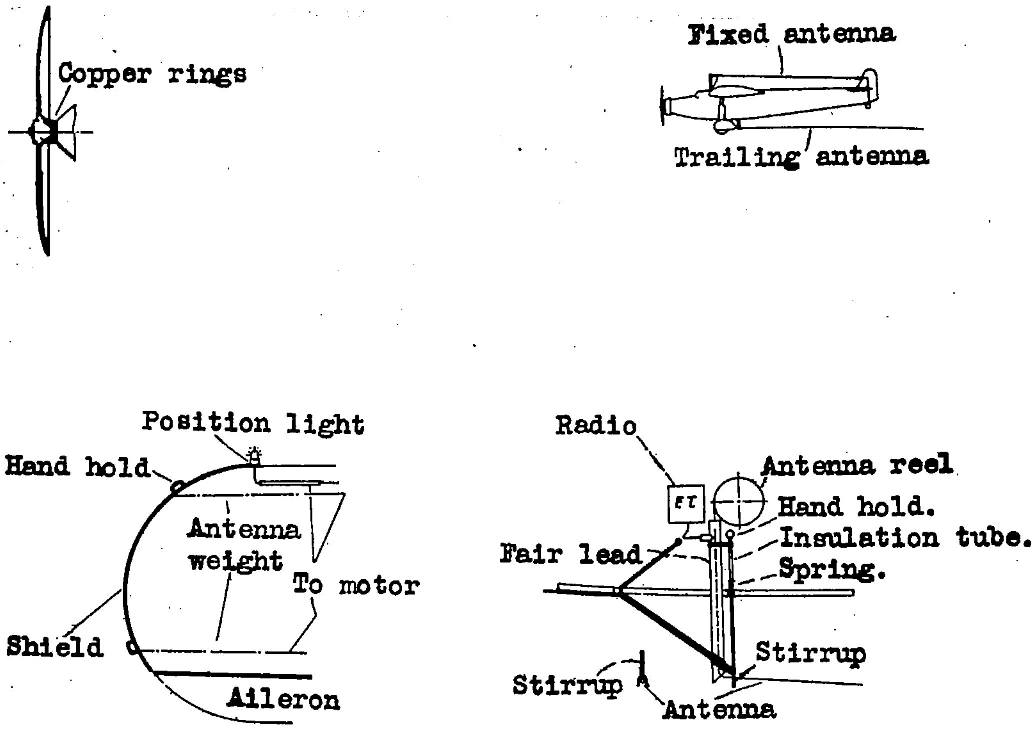


Figure 19.- Lightning protection for airplane, radio, wings, and propeller.

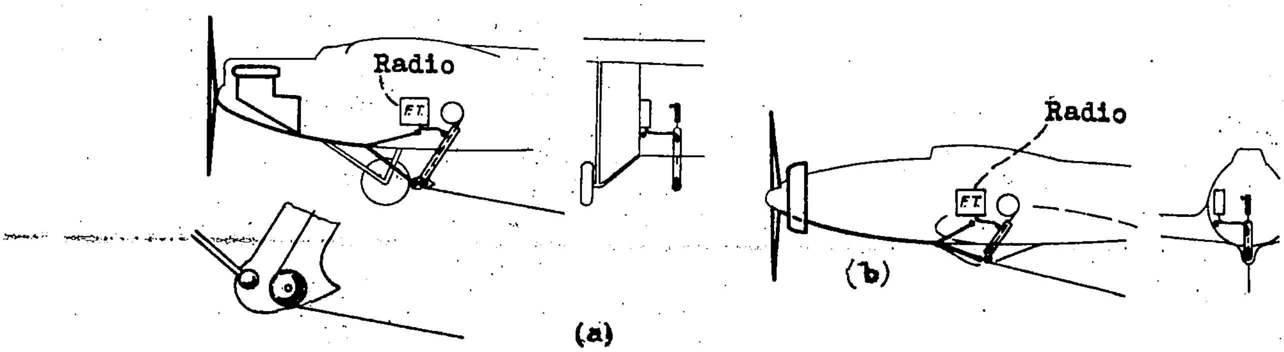


Figure 20.- Lightning protection for airplanes with retractable landing gear.